Design and Fabrication of a low cost Remotely Operated Underwater Vehicle for underwater exploration

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Abstract

Robotic systems and remotely operated mechanisms have gained increased application in the past years. Such systems are extensively used to replace or reduce human effort wherever possible. This paper aims at the design considerations and methodology used in manufacturing of a low-cost inhouse underwater remotely operated vehicle (ROV). The ROV can be used for inspection of underwater structures, pipelines and fishery cages, equipped with a camera and a Raspberry Pi board that can relay a live video feed from the ROV's perspective. Minimal number of DC motors fitted with propellors are used to propel the ROV in two translation directions and about one rotational axis. The ROV is controlled over WiFi with an Secure Shell (SSH) terminal on a portable computer. The prototype was validated for stability and maneuverabilty with experimental testing. A brief cost report of the project is also tabulated.

NOMENCLATURE			
ROV	Remotely operated vehicle	INR	Indian Rupee
DOF	Degrees of Freedom	SMPS	Switch Mode Power Supply
PVC	Poly-Vinyl Chloride	SSH	Secure Shell
USB	Universal Serial Bus	V	Volume of fluid displaced (m^3)
rpm	Revolutions per minute	g	Acceleration due to gravity (m/s^2)
C_d	Coefficent of drag	**Greek Symbols**	
GPIO	General Purpose Input Output	ρ	Density (kg/m^3)

1. INTRODUCTION

About 71% of earth's surface is covered by water. With technological development, underwater and off-shore structures were built for various purposes such as transportation, mining and fishery. Due to the harsh nature of sea water, these structures are exposed to corrosion, cracks, vibrations and fatigue damage. Human divers are conventionally employed in need of maintenance inspection of ship hulls, off-shore structures, underwater transportation pipelines, fishery cages and biological phenomenon. This conventional strategy has several limitations. First, the diver has to be trained for a particular operation. The duration of the operation is limited by the oxygen supply and the time our human body can withstand underwater pressures. Hence, a viable alternative to carry out such operations effectively are aquatic robots. The objective of this project is to design and develop a low-cost aquatic robot capable of surveillance or inspection.

Remotely operated underwater vehicles have been extensively used in underwater applications such as patrolling, monitoring and mechanical intervention when equipped with a robotic arms or grippers. Anuradha [1] developed an aquatic robot that can monitor water pollutants using a computer vision algorithm. In 2015, a remotely operated underwater vehicle called Nemo was developed for the inspection of a ship wreck. ROV control theory and Nemo's hardware and software capabilities are explained in the paper [2]. In [3], an autonomous underwater vehicle was designed and developed for regular fish-cage net inspection. A box type ROV's design and construction was proposed in [4]. The ROV used PVC for its frame and had six propellers for its locomotion while being operated wirelessly. An ROV used for underwater inspection tanks was developed by Alok Sahu [5]. The ROV had a torpedo frame design using 3D-printed clamps to mount the thrusters. Two thrusters were used for translational motion in the X axis and rotational motion in the Y axis. Two more thrusters were attached vertically for translational motion in the Y axis. A low-cost underwater robot with grippers that can be used to mount the robot onto the external surface of a pipeline and perform visual inspection of the same with a camera was developed [6]. The robot was tethered for power supply and control. The robot had five propellers for surge, sway and heave motions. From the literature survey, ROVs had six basic systems namely the structure, ballast, propulsion, power, control and navigation/sensors. For inspection applications, a camera is mounted on the robot and any added feature to the robot would be a mechanical device for intervention. Such application requires image stability more than quick maneuverability. Hence a box type ROV would perform better than a torpedo type ROV, because of the relatively high buoyancy gradient. Buoyancy gradient is defined as the distance between the center of gravity and the center of buoyancy. Also, the ROV should be slightly positively buoyant such that it can float before it sinks. The ROVs lacked a ballast system that would allow the robot to sink to depths and this limited their operable depth range. The ROVs discussed above were expensive in manufacturing. Hence, a low-cost aquatic robot is designed to provide stability and maneuverability under water with the least number of thrusters to achieve 6 degrees of freedom.

2. METHODOLOGY

2.1. Materials Consideration

The operating environment poses several problems like corrosion, pressure, temperature, currents, tides, entanglement in plant life underwater, salinity, etc. The materials used in construction of the ROV should be resistant to any variation of pressure and temperature within design range and should be resistant to corrosion. In accordance with the discussion above, PVC tubes and fitting accessories were used for construction of the frame. Similarly plastic housings were used for motors and electronic components. Plastic is a good solution

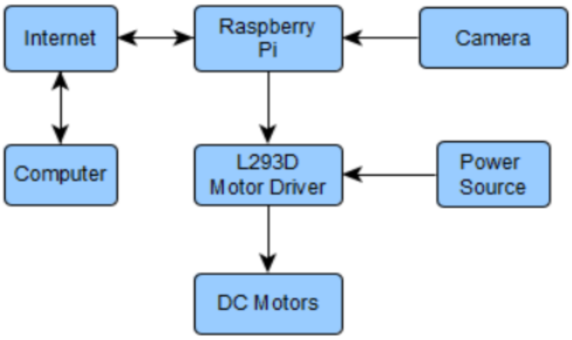

Figure 1. Hardware Block Diagram of the ROV

since they don’t chemically react with water at ambient conditions and are resistant to corrosion too.

2.2. Software and Hardware Design

The ROV’s hardware consists of two systems, one responsible for its movement and the other is responsible for transmitting a live video of the ROV’s perspective to a portable computer which is located above water surface. The ROV is tethered to a 12V power supply above water surface to power the three DC motors onboard. Onboard power supply is not used as it would make the ROV heavy, hence requiring more powerful motors increasing the cost. Three identical 12V 300rpm DC motors were used, two responsible for surge and sway motion while the other is used for sink motion. L293D motor driver circuits were used to actuate the motors. Motor driver is controlled by GPIO pins on the Raspberry Pi board. A python program is used to actuate the motor using keys on the computer’s keyboard. The Raspberry Pi is connected to the computer using a SSH terminal over WiFi. This enables us to remotely control the Pi with a computer hosting a WiFi hotspot. An action camera is connected to the Pi’s USB port and functions like a web camera. The Pi is also used as a webcam server and live video feed can be obtained using any web browser on the remote computer.

2.3. Mechanical Design

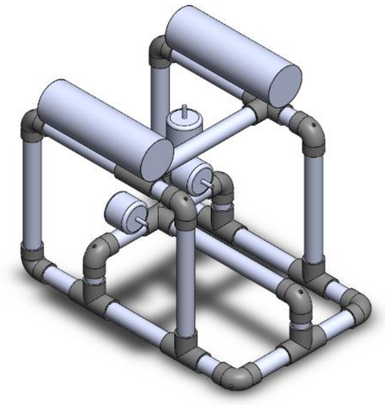

Figure 2. CAD design of the ROV

The ROV’s overall dimensions are 43cm in length, 28cm wide and 33cm high. The frame is made from PVC tubes of one inch outer diameter and 3mm thickness. Drain holes are made onto the frame members at regular intervals to allow for better sinking as well as to drain the water inside the frame after an underwater operation. The cage structure protects the propellor blades and housings from direct external impacts. Plastic casings that housed the motors were fastened to the frame using brass U-clamps and fasteners. Brass does not rust. The frame is designed in such a way that the centre of gravity and the centre of bouyancy are placed at an optimal distance from each other resulting in good stability when immersed. The distance between the centre of gravity and the centre of bouyancy is called bouyancy gradient. Plastic waterproof casings were used as floats to make the ROV slightly positively bouyant. This is done so that the ROV does not sink in case of any system failure and always rises to the water surface. Bouyant force for any immersed object is derived through Equation (1).

$$B = \rho * \mathrm{V} * \mathrm{g} \quad (1)$$

Where ρ is density of fluid, V is volume of fluid displaced and g is acceleration due to gravity. The bouyant force is greater than the weight of the fluid displaced for the object to be positively bouyant.

A static ballast system is used to permit sinking, where a thruster is used to push the positively bouyant ROV to depths. Tribladed propellors are attached to the motor shafts and act as thrusters for the ROV. Thrust generated is able to overcome inertia as well as the drag and pressure forces underwater. A symmetric design assures no roll and undesired pitch is trimmed by adjusting the floats and weights experimentally.

2.4. Test Motion

The underwater ROV is tested for surge and sway motion. After sufficent balancing for floats, the speed and stabilty is evaluated and found to be sufficient to carry out a underwater inspection or surveillance operation. Similarly the sink motion is also tested.

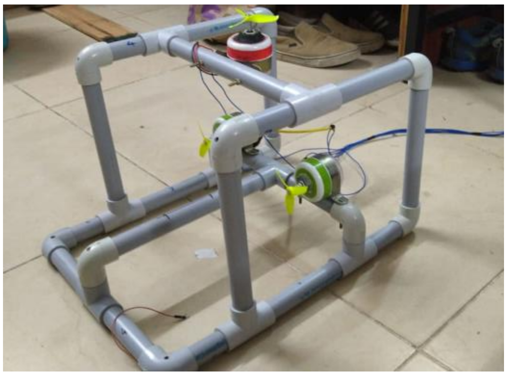

Figure 3. Mechanical design of the ROV

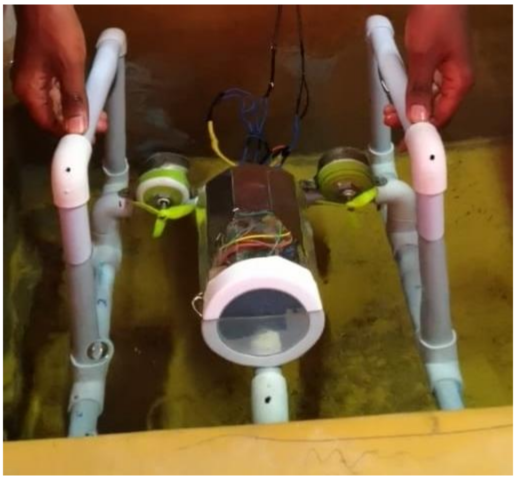

Figure 4. Stability testing of the ROV

3. RESULTS AND DISCUSSION

3.1. Experimental Study

An immersion test was preliminarily performed to check water tightness in the motor and electronic component housings. Then the pitch of the ROV was trimmed by adjusting the float's position. When the ROV is stable at rest, the Pi is powered up and a WiFi connection is established on boot up. Using the python program in the remote computer, surge, sway and sink motion are individually performed and the speeds are observed. A maximum speed of 0.1m/s was observed for surge motion in the forward direction. A POV feed of the camera was also relayed to the remote computer. The duration of operation is entirely dependent on the power supply supplied through the tether.

Figure 5. Experimental testing of the ROV (Sway)

Figure 6. Experimental testing of the ROV (Surge)

3.2. Cost Analysis

An estimation of cost was performed based on the items used for the project. The total cost of the underwater ROV is briefly shown in **TABLE 1** below.

TABLE 1.Cost Description

Item	**Cost in INR**
Raspberry Pi	3000
12v SMPS	300
HD Action Camera	700
12V DC Motors	500
Propellors	200
Fabrication Costs	1000
Total	**5700**

4. CONCLUSION

A CAD model of the underwater ROV was designed after adequate literature studies. Wireless communication was established for remote control and video feed and the electrical and electronic hardware were placed in waterproof casings and integrated with the ROV’s frame. Floats were added to the ROV to act as a ballast system after several tests on stability and bouyancy. The functionality of the underwater ROV was experimentally validated. Further work can be focused on developing a low-cost dynamic ballast system and an onboard power supply eliminating the need for a tether.

5. REFERENCES

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